Mem. Natl Inst. Polar Res., Spec. Issue, **56**, 142–147, 2002

Hydraulic resistance to movement of a drill suspended by a cable in a bore-hole in travels

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Abstract: Equations are given for calculation of the hydraulic resistance force to movement of a drill suspended by cable and the speed of its movement as a function of the dimension and mass of the drill and properties of the hole liquid. The most significant factor influencing the hydraulic resistance during drill movement in the hole is the radial clearance between the drill and bore-hole walls. The methods of experimental study of the drill movement on the laboratory stand are described. The results of the theoretical calculations and measurements of the speed of the drill movement obtained during drilling on Vavilov glacier (Severnaya Zemlya archipelago) are compared: the discrepancy does not exceed 10%.

Deep ice drilling in the Arctic and in Antarctica is carried out, basically, by an electromechanical or electrothermal drill suspended by a cable. To prevent bore-hole closure, deep ice holes are filled by a fluid creating hydrostatic backpressure. To hoist the drill to the surface after each run to recover chips and the core takes from 50 up to 90% of the total drilling time, creating an urgent need to increase the travel speed. This makes it necessary to know the law of motion of the drill in the hole under action of the forces on it, in particular the force of hydraulic resistance.

The movement of the drill in a hole filled by liquid is similar to the movement of a wire-line drill or the movement (Isaev and Onicshin, 1975) of a core during hydraulic transport (Gluchov *et al.*, 1987). One of the differences is that an ice core drill, in particular an electromechanical drill KEMS-112 (Kudryashov *et al.*, 1994), is centered on the hole axis by the antitorque system, and the core and the demountable coreholder are free to move in the radial direction, so that they can contact the wall of the hole or tube.

It is possible to determine the force of hydraulic resistance resisting the movement of the drill, as the sum of the forces under the drill and above it, friction force of the drill in the fluid and losses due to stress on the butt ends of the drill when transient phenomena occur the fluid, which one can be taken into account by a correction factor K.

We have:

$$P_p = \Delta p \pi r^2, \tag{1}$$

$$P_f = 2\pi r l \tau_1, \tag{2}$$

where P_p is the force due to the difference of stresses under the drill and above it in newtons (N); P_f is the friction force of the drill in the fluid in N; Δp is the differential stress on the butt ends of the drill in N/m^2; r is the radius of the drill in m; τ_1 is the tangent stress in a thin stratum of fluid on the surface of the drill in Pa.

$$P_p + P_f = \Delta p \pi r^2 + 2\pi r l \tau_1. \tag{3}$$

During movement of a drill in a filled hole (Gukasov, 1982) the equation for tangent stress is expressed as a following equation,

$$\tau_1 = \frac{a(2r+a)}{2rl} \Delta p, \tag{4}$$

where a is the interval between drill surface and wall of the hole, m.

Use of the eq. (4) is difficult because the analytical expression for a, obtained from transcendental equations is complicated. According to Gukasov (1982) the relative interval between the drill surface and the neutral stratum $\bar{a} = a/r$ at different values of relative radial clearance $\bar{\delta} = \delta/r$ are resulted in the tabulared shape. After treating these tabulared data with a square method we receive

$$\bar{a} = 0.74 \bar{\delta}^{1.14}. \tag{5}$$

Thus, the tangent stress in fluid on the drill surface can be determined by using the geometrical characteristics of drill, radial clearance and differential of stresses.

The differential stresses we determine using the formula of Darcey:

$$\Delta p = \lambda \frac{\rho v_f^2 l}{r_1 - r}, \tag{6}$$

where λ is the coefficient of hydraulic resistance; ρ is density of the fluid, kg/m^3; r_1 is the radius of the hole, m; v_f is the rate of flow of fluid in an annular space m/s.

In the fluid in the constrained annular space, the turbulent condition occurs at values of Reynolds number more than 1600, hence, in the practical range of variation, at the speed of tripping (Table 1) the flow in the gap between drill surface and hole wall will be turbulent.

Considering that at working values of the Reynolds number and radial clearance the surface of the drill is smooth hydraulically (Gukasov, 1982), the coefficient of hydraulic resistances can be determined using Blasius's formula:

$$\lambda = 0.2661 \frac{\nu^{0.25}}{(r_1 - r)^{0.25} v_f^{0.25}}, \tag{7}$$

Table 1. Characteristics of deep ice drilling.

Characteristics of drill	Diameter of drill, m	
	0.108	0.146
Length of drill, m	6-13	
Radial clearance, m	0.003-0.014	0.004-0.018
Coefficient of kinematic viscosity of fluid , m^2/s	$3*10^{-6}$-$5*10^{-6}$	
Speed of tripping, m/s	0.1-1.0	
Reynolds number	1000-17800	1300-24000
Relative radial clearance	0.053-0.25	
Ratio of length of drill to radial clearance	340-4000	

where ν is the coefficient of kinematic viscosity of fluid, m^2/s.

Substituting eq. (7) in to eq. (6) and expressing v_f through speed of movement of drill using v the equation of indissolubility (Gukasov, 1982), we receive

$$\Delta p = 5.88 \cdot 10^{-3} \nu^{0.25} \rho l d^{1.75} \delta^{-3} \left(1 + \frac{\delta}{d}\right)^{-1.75} v^{1.75}, \tag{8}$$

where $\delta = r_1 - r$; d is the diameter of the drill, m.

Substituting eq. (4) in to formula (3), we obtain

$$P_p + P_f = \Delta p \pi r^2 + 2\pi r l \tau_1 = \pi (r + a)^2 \Delta p. \tag{9}$$

Then using eq. (5) and coefficient K,

$$P_h = K\pi r^2 (1 + 0.74\bar{\delta}^{1.14})^2 \Delta p, \tag{10}$$

and using eq. (8)

$$P_h = \hat{E}\beta v^{1.75}, \tag{11}$$

where

$$\beta = 4.62 \cdot 10^{-3} \left[1 + 1.63\left(\frac{\delta}{d}\right)^{1.14}\right]^2 \nu^{0.25} \rho l d^{3.75} \delta^{-3} \left(1 + \frac{\delta}{d}\right)^{-1.75}. \tag{12}$$

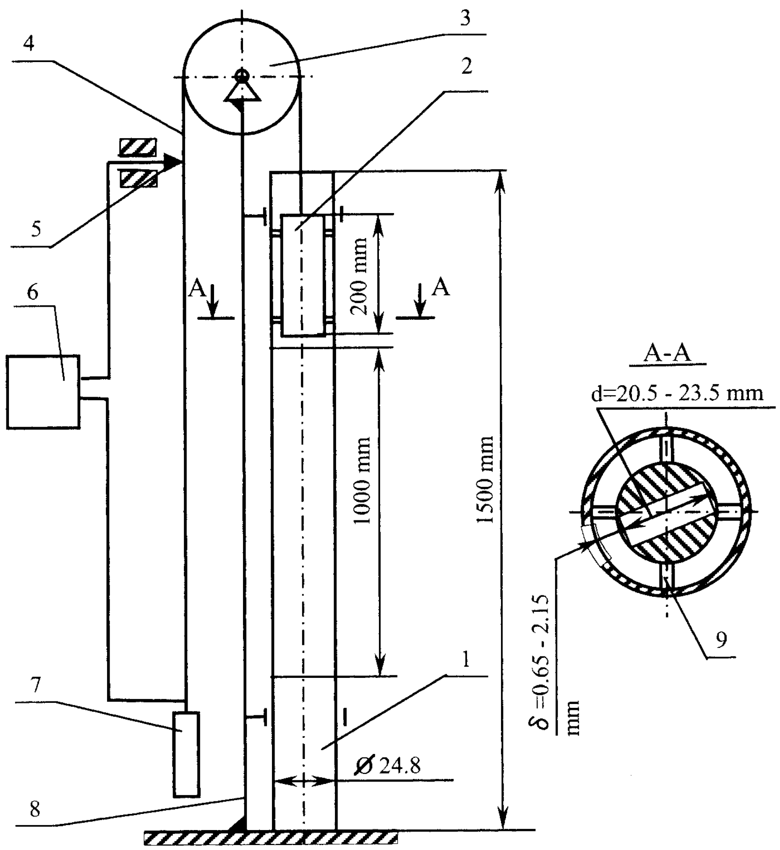

Fig. 1. Scheme of the testing stand.
1-bottom of hole; 2-model of drill; 3-roller; 4-flexible link; 5-immobile contact; 6-recorder; 7-weight; 8-post; 9-center-guide.

For definition of coefficient K, experiments were carried out in order to study the process of movement of a model drill on the laboratory stand (Fig. 1). The experiment results are summarized in Tables 1 and 2.

The model of drill 2 is pulled down on the bottom of hole I, the weight 7 is fixed in the upper position. After releasing weight 7 it, being lowered, hoists, with the help of the flexible link 4, the model of drill 2. A stainless steel line of diameter 0.3 mm is used as the flexible link. The movement of the drill model was recorded using a self-recorder of voltmeter H-302I type by measuring the resistance of a flexible line between immobile contact 5 and weight 7.

Experiments have shown that forces of hydraulic resistance practically instantly equilibrate with driving forces and the model drill moves with constant speed.

Hence,

$$P_h = F, \tag{13}$$

where F is the driving force in N applyed to the model drill.

The value of coefficient K can be estimated from the equation

$$\hat{E} = \frac{F}{\beta v_m^{1.75}}, \tag{14}$$

where v_m is travelling speed of the model drill in m/s.

The results of the experiments showed that coefficient K can be expressed as a function of relative radial clearance $\bar{\delta}$. The results of experimental studies using eq. (14) are placed in Table 3. In Fig. 2 the curve $K = K(\bar{\delta})$ and experimental points are shown. Each experimental point is a mean value of model drill speed during five experiments with the

Table 2. Characteristics of the stand for study of drill movement in the hole.

Characteristics	Diameter of drill model, m				
	0.0235	0.0228	0.0225	0.0222	0.0205
Model of hole:					
length, m			1.5		
length of gaging interval, m			1.0		
inside diameter, m			0.0248		
Fluid (distillated water):					
Coefficient of kinematic viscosity, 10^{-6} m^2/s			1.0		
density, kg/m^3			1000		
Mass of weight, kg			0.677		
Model of drill:					
length, m			0.2		
mass, kg	0.239	0.227	0.209	0.211	0.181
Radial clearance, 10^{-3} m	0.65	1.00	1.15	1.30	2.15
Relative radial clearance	0.0553	0.0877	0.1020	0.1170	0.2100
Ratio of length of model drill to radial clearance	308	200	174	154	93

Table 3. Results of experimental study of model drill movement on the laboratory stand. ($\rho = 1000$ kg/m^3; $\nu = 10^{-6}$ m^2/s)

$\bar{\delta}$	Re	δ, 10^{-3} m	d, m	β, N(s/m)$^{1.75}$	F, N	v_m, m/s	K
0.0553	1680	0.65	0.0235	83.20	5.194	0.147	1.79
0.0877	3120	1.00	0.0228	20.57	5.259	0.286	2.29
0.1020	4090	1.15	0.0225	12.02	5.410	0.382	2.26
0.1170	4720	1.30	0.0222	8.55	5.369	0.450	2.54
0.2100	9280	2.15	0.0205	1.45	5.507	1.000	3.80

same initial parameters.

Equation

$$K = 1.05 + 13\bar{\delta}, \tag{15}$$

is obtained as a result of treating the experimental data.

Comparision of speed of the drill in the hole drilled in Vavilov Glacier on Severnaya Zemlya in 1988, and experimental data, showed that the discrepancy between experimental and *in situ* data does not exceed 10% (Fig. 2).

Let us designate

$$\beta_1 = K\beta, \tag{16}$$

Then eq. (11) will be

$$P_h = \beta_1 v^{1.75}, \tag{17}$$

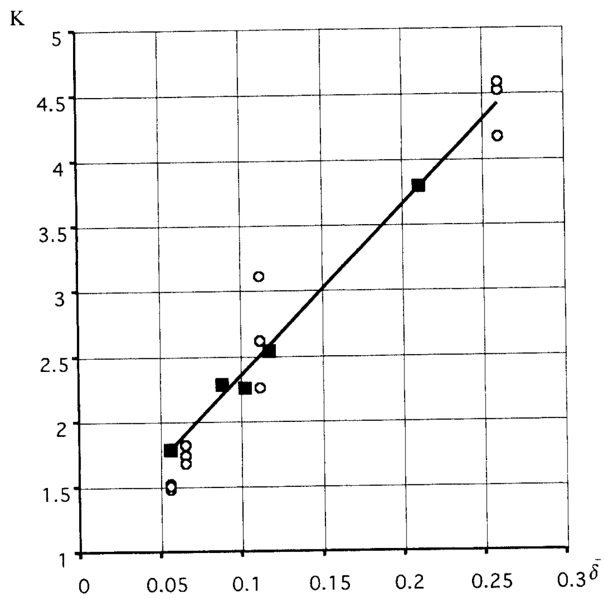

Fig. 2. Coefficient K versus relative clearance:
■*-based on stand investigations;* ○*-based on results of drilling.*

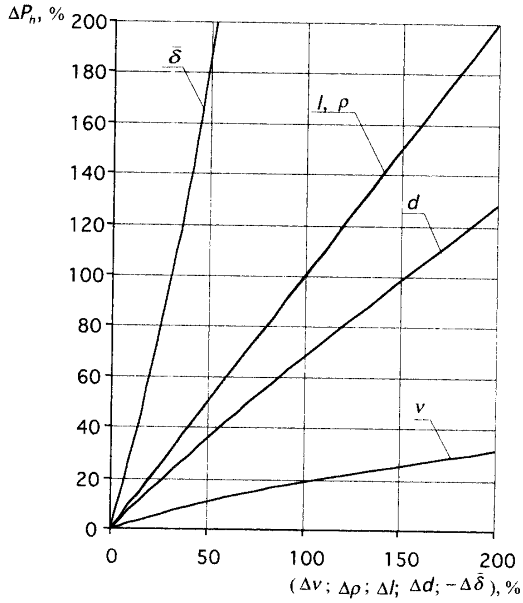

Fig. 3. Relative change of hydraulic resistance versus relative changes in other factors.

where β_1 is the coefficient that takes into account the geometrical characteristics of drill and hole, and also properties of the fluid.

Substituting eqs. (12) and (15) in to eq. (16), we obtain

$$\beta_1 = 4.62 \cdot 10^{-3}\left(1.05 + 26\frac{\delta}{d}\right)\left[1 + 1.63\left(\frac{\delta}{d}\right)^{1.14}\right]\nu^{0.25}\rho l d^{3.75}\delta^{-3}\left(1 + \frac{\delta}{d}\right)^{-1.75}, \tag{18}$$

or

$$\beta_1 = 0.037(1.05 + 13\bar{\delta})\ (1 + 0.74\bar{\delta}^{1.14})^2\gamma^{0.25}\rho l d^{0.75}\bar{\delta}^{-3}(1 + \bar{\delta})^{-1.75}. \tag{19}$$

The analysis of these equations (Fig. 3) showed that the most significant factor influencing the hydraulic resistance during drill movement in the hole is the relative radial clearance or, at a constant drill diameter, radial clearance.

References

Gluchov, V.I., Kukes, A.I. and Petrov, A.A. (1987): Dvigenie kerna v voschodiacshem potoke promivochnoi gidkosti. V sb.: Sovershenstvovanie i vnedrenie tecshnologii promivki i tamponirovania skvagin v usloviacsh Vostochnoi Sibiri i Kraynego Severa. Leningrad, VITR, 57–65 (in Russian).

Gukasov, N.A. (1982): Hydraulics handbook in drilling. Moscow, Nedra, 1–302 (in Russian).

Isaev, M.I. and Onicshin, V.P. (1975): Burenie so semnimi kernopriemnikami. Leningrad, Nedra, 1–128 (in Russian).

Kudryashov, B.B., Vasiliev, N.I. and Talalay, P.G. (1994): KEMS-112 electromechanical ice core drill. Mem. Natl Inst. Polar Res., Spec. Issue, **49**, 138–152.

Makovey, N. (1986): Hydraulics in drilling. Moscow, Nedra, 1–505 (in Russian).

(Received March 5, 2001; Revised manuscript accepted September 26, 2001)